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Field-store standards conversion: an improved instrumentation for the frequency modulation system

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D. Maurice

R.E. Davies, M.A.

Head of Research Department

(EL-25)

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FIELD STORE STANDARDS CONVERSION : AN IMPROVED INSTRUMENTATION FOR THE FREQUENCY MODULATION SYSTEM

SUMMARY

An improved F.M. modulator and demodulator are described which are suitable for the transmission of television signals through a field-store standards converter. They represent an improvement on an earlier instrumentation and in particular, give good overall linearity and are easier to align. The modulator is conventional in form but the demodulator consists of a servo-loop which maintains the output signal from a second, identical modulator in phase-lock with the r.f. modulated signal frequency.

1. INTRODUCTION

One way of instrumenting a frequency modulation system for television signal transmission was described in an earlier report.[1] The modulator consisted of an oscillator whose frequency was varied by applying the television signal as a variable reverse bias to a varactor diode in the frequency determining tuned circuit. The demodulator consisted of a limiter a discriminator, a low-pass filter and video amplifier. The discriminator contained two tuned circuits whose outputs were rectified and subtracted to form the demodulated signal. By adjusting the centre-frequencies and bandwidths of the tuned circuits it was possible to obtain an output signal whose video frequency component varied linearly with input modulated signal frequency to the discriminator.

The earlier design suffered from one intrinsic difficulty in that the modulator varied the signal frequency in a non-linear manner with respect to the level of the input video signal, whereas, in the demodulator, the level of the output video signal was linearly related to the incoming signal; thus the overall system was non-linear. In addition to overcoming this difficulty several practical problems have been avoided, namely:

1) The gain of the limiter need not be as high and thus the circuits are less prone to instability.
2) In the former system the output video signal from the discriminator was small compared with the unwanted carrier component whereas in the new system, the output video signal is of standard amplitude (0·7 volts) and the unwanted carrier at a much lower level. Thus the use of high gain video amplifiers and low-pass filters with high rejection-ratio is avoided.
3) The discriminator in the former system required alignment of four circuit parameters to obtain the required overall video response, whereas in the new system only two adjustments are necessary.

2. DESCRIPTION OF THE SYSTEM

2.1. The Modulator

The modulator is identical with that described in Ref. 1. The modulation frequency is controlled by a parallel tuned circuit in which the capacitance is a varactor diode to which the modulating video signal is applied as a variable reverse bias. Under these conditions its capacitance varies with bias so that the oscillator frequency changes with the applied video signal voltage. In practice, with a frequency deviation of about ± 0·5 MHz about a centre frequency of 30 MHz, the law relating output frequency to input video signal shows slight non-linearity (of the order of 5%).

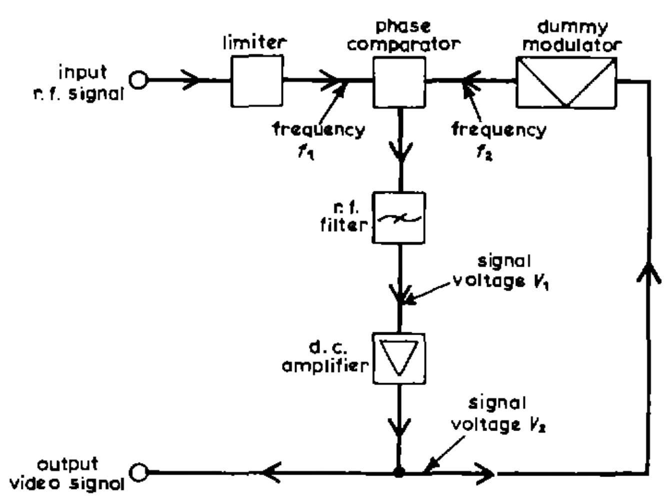

Fig. 1 - Block diagram of the demodulator

2.2. The Demodulator

Fig. 1 shows a block diagram of the demodulation system. The input r.f. signal is applied to a limiter and thence to a phase-comparator where its phase is compared in a balanced diode-bridge with the phase of a second r.f. signal from a dummy modulator. The dummy modulator is identical in circuit and layout with the modulator proper in order that it shall have the same law relating input video signal to output frequency. The output signal from the phase comparator consists of a video frequency component which varies linearly with the phase difference between the two r.f. input signals over a moderate range of phases, and an r.f. component containing mainly the harmonics of input frequencies. The latter component is removed in an r.f. filter and the former component is amplified and fed back to the dummy modulator.

The loop containing the dummy modulator, phase-comparator, r.f. filter, and d.c. amplifier is similar in principle to a servo system and is arranged so that the feedback is negative; this configuration is sometimes referred to as a phase-locked oscillator. Thus the phases of the incoming r.f. signal and the r.f. signal output from the dummy modulator remain locked and consequently the frequencies of these signals are identical. If, then, the dummy modulator and the main modulator are identical, the input signals to each must also be identical; that is, the output video signal from the demodulator is identical with the input video signal to the modulator.

3. THEORETICAL PERFORMANCE OF THE IMPROVED INSTRUMENTATION

3.1. Response at Low Video Frequencies

It is clear that for low-frequency modulating signals for which the loop-phase shift is negligible, the r.f. signala will be maintained in phase-lock (provided the component circuits of the demodulator can cover the required signal range). Thus the output video signal will be identical with the input video signal if the input signal/output frequency laws of the two modulators are the same.

3.2. Response at High Video Frequencies

For high video modulating frequencies (several MHz) the phase-shift round the servo loop is no longer negligible and to estimate the performance it is necessary to analyse the behaviour in terms of the loop gain and time constants in the loop, as for example, in designing a feedback amplifier. The analysis is carried out in the Appendix. It is shown that a maximally-flat video frequency response can be obtained in the case where a single R–C combination is present, producing a lag with a certain time-constant. This case is a reasonable approximation to the practical equipment in which the r.f. filter may have a time-constant which results in appreciable phase-shift in the video band and the other circuits can be made sufficiently broadband to have negligible phase-shift. If the time constant is given, the loop gain must be adjusted to obtain the maximally-flat response and the cut-off frequency is then dependent on the value of the time-constant.

3.3. The Need for a Limiter

In principle the phase-comparator is required to be sensitive only to the phase of the input signal. However, practical phase-comparators give an output signal which is proportional to both input amplitude and phase. The effect of variations of input amplitude would be to change the sensitivity of the phase-comparator and consequently the loop gain. It is shown in the Appendix that a change in loop gain will alter the video frequency-response of the demodulator. It will not, however, affect the video output level as in a conventional form of demodulator and, consequently, the limiter required for this system need not have so high a rejection. This feature is particularly valuable in applications such as Field-Store Standards conversion,[2] in which the sensitivity to errors in gain is greater than the sensitivity to errors in frequency response.[3]

3.4. The r.f. Filter

As was explained in Section 3.2, it is important that the phase-shift of the r.f. filter at video frequencies shall not be too great since this would result in reduced video bandwidth. Consequently, it was decided to use a simple notch filter, tuned to the second harmonic of the carrier frequency which is the predominant r.f. component in the phase-comparator output signal. It was found experimentally that a reduction of the r.f. level of about 20 dB was obtainable and that the resulting time constant corresponded to a video response/frequency characteristic falling to −3 dB at 6 Mc/s, a performance adequate for television signals of either American or British standards.

3.5. Effect of Modulator Non-Linearity

As shown in Section 2.2, even though the output frequency from the modulator is not linearly related to the video input signal, nevertheless the overall response of the modulator/demodulator combination is linear at low frequencies. This is because the modulator and dummy modulator have identical characteristics and the demodulator servo-loop is able to follow the slow variations of input signal frequency nearly perfectly.

However, if the modulating video frequency is high so that the frequency of the modulated carrier changes rapidly, then the servo-loop is no longer able to follow perfectly on account of its phase shift. Variations in the dummy modulator frequency always slightly lag behind the input signal variations and

under such conditions harmonics of the modulating frequency are generated in the output signal. For example, a 2 MHz modulating sine wave produces r.f. frequency variations at 2 MHz, 4 MHz and higher harmonics on account of the non-linearity of the modulator. The dummy modulator attempts to follow these variations but, due to the phase-shift between the phase-comparator and the dummy modulator, the reproduced variations of frequency lag those at the other input to the comparator and the 2 MHz signal reappears at the output together with a spurious 4 MHz component. In practice the spurious component is about 5% of the amplitude of the main component when a sine wave input of maximum amplitude is applied. The effect is unimportant in practice and does not give visible distortion of normal pictures.

4. THE PRACTICAL EQUIPMENT

A practical equipment was developed using the above principles for use in the advanced field-store standards converter. The following system parameters were chosen:

Carrier frequency = 32 MHz for mid-grey signal level

Deviation = 0·5 MHz

The performance of the equipment is summarised below:

Video response/frequency characteristic:—

± 0·2 dB from 0 to 5 MHz
−1 dB at 5·5 MHz
−3 dB at 6 MHz

Linearity (on sawtooth signal) within 1%

A.m. rejection:—

Less than 0·1 dB variation of video signal with 10 dB change of r.f. signal level.

5. CONCLUSIONS

The f.m. modulator and demodulator are suitable for television signal transmission in the Field-Store Standards Converter and have several advantages over the equipment described in Ref. 1. Better overall linearity is obtained and the design and alignment present fewer problems.

6. REFERENCES

1. The transmission of television signals in a narrow bandwidth using frequency modulation. Research Department Report No. T-170, Serial No. 1966/33.

2. A field-store converter using ultrasonic delays as the storage medium. Research Department Report No. T-136, Serial No. 1964/65.

3. Field-store standards conversion: a comparison of amplitude and frequency modulation systems, Research Department Report No. T-166, Serial No. 1966/14.

APPENDIX

The Response of the Servo-Loop in Terms of its Gain and Time Constants

Suppose that the r.f. filter and d.c. amplifier together (see Fig. 1) have a response:

$$V_2 = V_1 A/(1 + p\tau) \qquad (1)$$

Where V_1 and V_2 are the input and output voltages respectively, A is the amplifier gain, τ a time constant in the chain and p the operational variable (equal to d/dt or $j\omega$).

Suppose also that the modulator has a response:

$$f = \alpha V_2 \qquad (2)$$

Where f is the output frequency, V_2 is the input modulating voltage across the varactor and α a constant having the appropriate dimensions. The phase-comparator is assumed to be linear for small differences in the phases of its two input signals and has an l.f. response;

$$V_1 = b(f_1 - f_2)/p \qquad (3)$$

Where f_1 and f_2 are the input frequencies, b an appropriately dimensioned constant. The factor 1/p is necessary since the output is proportional to phase-difference and phase is the integral of frequency. The servo-loop equation may be written:

$$f_2 = \alpha \cdot \frac{A}{1 + p\tau} \cdot b \frac{1}{p} (f_1 - f_2) \qquad (4)$$

where f_2 is now identified as the dummy modulator frequency and f_1 the input radio frequency to the demodulation system.* For simplicity we may now lump αAb into one constant, say A', which is the overall loop gain. (It should be noted that A' has the dimen-

* The offset frequency equal to the centre carrier frequency has been omitted since only l.f. modulations are being considered.

sions of frequency). Hence

$$f_2 = A'(f_1 - f_2)/\mathrm{p}\,(1 + \mathrm{p}\tau) \quad (5)$$

Therefore $$\left[1 + A'/\mathrm{p}(1 + \mathrm{p}\tau)\right] f_2 = A' f_1/\mathrm{p}(1 + \mathrm{p}\tau) \quad (6)$$

Therefore $$f_2 = f_1/\left[1 + \mathrm{p}(1 + \mathrm{p})/A'\right] \quad (7)$$

i.e. $$f_1/f_2 = 1 + \mathrm{p}/A' + \mathrm{p}^2\tau/A' \quad (6)$$

Equation (8) represents the overall response of the demodulator and it is desirable that it should be maximally flat in order to obtain a good video response.

The standard second order maximally flat response is:

$$1 + \mathrm{p}\sqrt{2}/w_0 + \mathrm{p}^2/w_0^2$$

$w_0/2\pi$ being the half-power or 3 dB point.

Thus in the servo-loop, A' and τ must be related by the equations:

$$\left.\begin{aligned} \frac{1}{A'} &= \frac{\sqrt{2}}{\omega_0} \\ \text{and} \qquad \frac{\tau}{A'} &= \frac{1}{\omega_0{}^2} \end{aligned}\right\} \quad (9)$$

which reduce to:

$$2A'\tau = 1 \quad (10)$$

The half-power frequency is given by:

$$w_0/2\pi = A'\sqrt{2}/2\pi = 1/2\pi\tau\sqrt{2} \quad (11)$$

JMP

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